Operating real equipments with fully simulated On Board Computer: SimEFM, a new validation infrastructure

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INTRODUCTION

In a classical Functional Validation approach, tests involving real spacecraft equipments are performed using large hardware test benches, known as Avionics Test Bench, "flatsat" or Electrical/Proto Flight Model benches (EFM/PFM). These benches include a hardware model of the On Board Computer and its associated EGSE in order to set up and control the Flight Software, which have an impact on the validation cost, schedule (availability of the hardware), and processes (only one Avionics Test Bench is available for all people involved in validation).

Alongside, numerical simulators are now widely used in satellite Functional Validation, as their performance and excellent fidelity allows activities ranging from Flight Software to space operations procedures validation. These simulators are all based on a fully representative numerical model of the On Board Computer (OBC), including an emulator of its processor, this model being associated to satellite equipments and payload models. They are low cost and versatile systems, easily deployed on Intel/Linux based PCs, available for a large number of people involved in the validation process.

Current Astrium OBC simulation performances allow faster-than-real-time execution on numerical simulators. Thus, the opportunity arises to execute the Flight Software under real-time conditions, with the capability to generate electrical signals (e.g. 1553 messages) to real equipments.

These performances make possible the so-called SimEFM configuration (standing for Simulated EFM bench), a mix of a numerical simulator (executing the real Flight Software in an OBC model) and some H/W interfaces (e.g Mil 1553 bus) used to control real equipments.

SimEFM : A NEW HYBRID VALIDATION INFRASTRUCTURE

Functional Validation infrastructures used all along the satellite validation process can be split in two families: numerical (or full SW) infrastructures where all equipments are simulated and hybrid ones where real equipments are operated and linked to simulations (dynamics, environment, missing equipments).

The use of numerical simulators is now well mastered all along the Functional Validation process, from the AOCS early studies up to flight software and spacecraft operations validation. Full numerical simulators are also used during in-orbit operations. These simulators are all based on the same architecture (Intel based PCs) and their core element is the OBC model which includes an emulator of its processor. This emulation allows executing in the OBC model exactly the same Flight Software (FSW) as the one used on the real computer, taken as a binary image file.

On the other hand, hybrid infrastructures are more complex due to the use of real equipments. They can be simple characterization test benches where equipments are connected to electrical interfaces similar to the ones existing on the On Board Computer. Or they can be complex test systems such as EFM and PFM benches that include at least one real OBC and the associated SCOEs required for the bench operations (such as TM/TC SCOEs, power SCOE, …).

Mixing these two existing infrastructures (full numerical and EFM hybrid configurations) gives the SimEFM test system, where real equipments are controlled by the real Flight Software running in a simulated OBC.

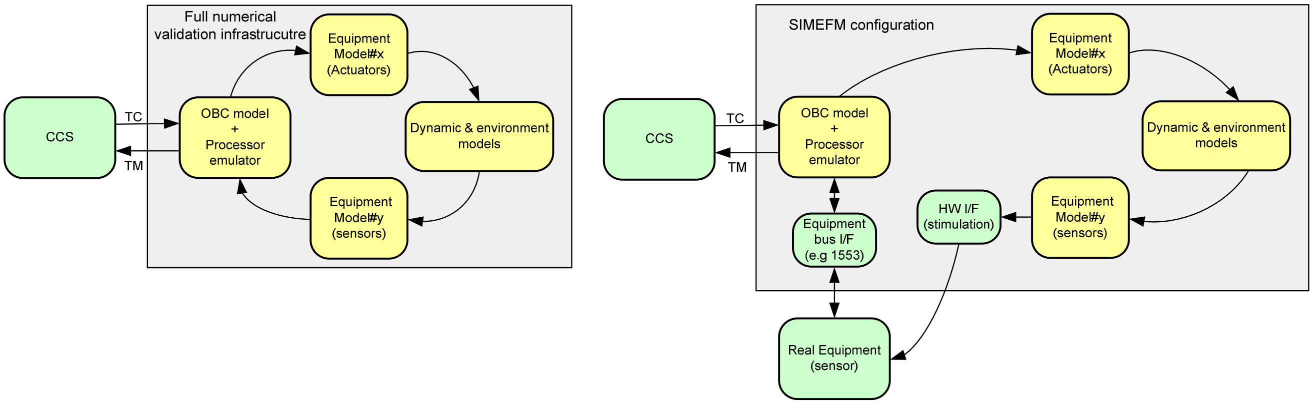

Fig. 1 : Comparison between full numerical simulator architecture and SimEFM, where real equipment (sensors, actuators or payload/intruments) are controlled by the simulated OBC

Equipments are operated as identical to EFM/PFM configuration (using the same TM/TC sequences), bringing the opportunity to perform SW-HW or HW-HW tests in a lighter configuration. Additional SCOEs such as TM/TC and Power are no more required for test setup and control.

By replacing the real OBC with a PC workstation (Linux based), this configuration can be used instead of classical test benches build around the OBC. Thus, SimEFM offers new opportunities in the overall validation process. Some validation activities can be performed in parallel on less complexes and less expansive benches.

SimEFM ARCHITECTURE

SimEFM is based on the generic Astrium simulation infrastructure (SimTG) like all other numerical or hybrid simulators used along the functional validation.

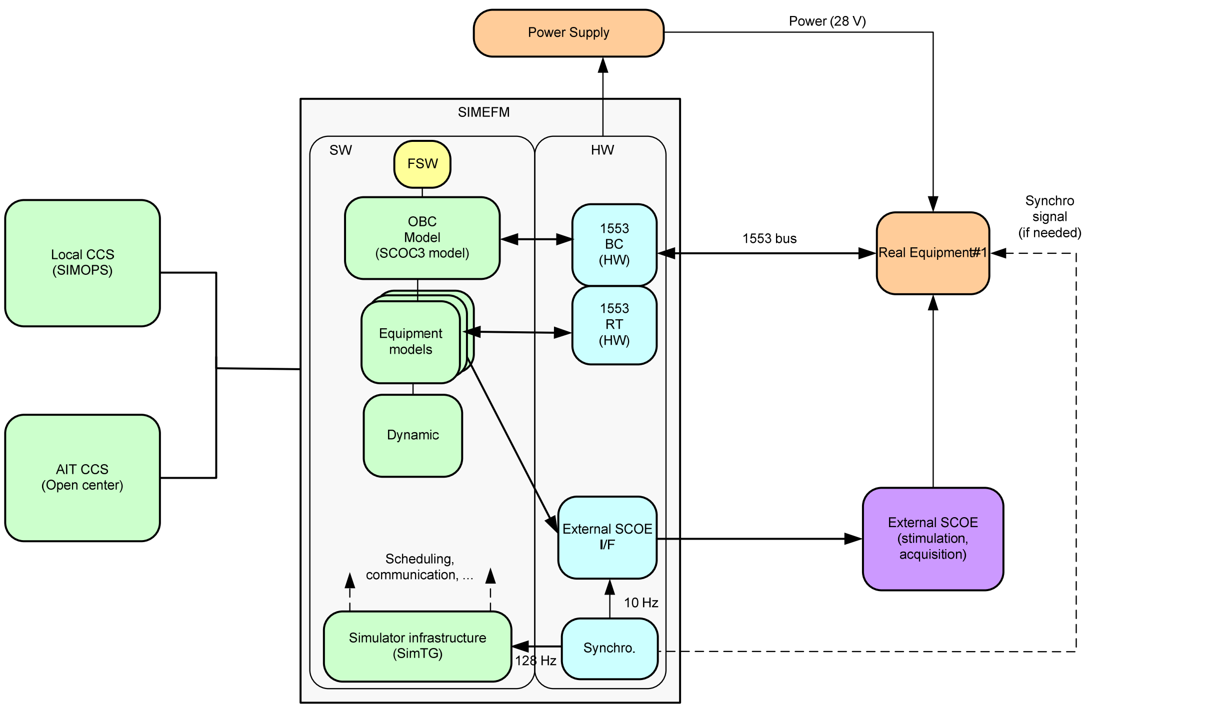

Fig. 2 : SimEFM overall architecture

SimEFM is part of the simulator product line and is mainly built with components shared with the other systems:

- Models, including OBC model and processor emulator, are fully reused. There is no development of model specifically required for SimEFM configuration.
- HW interfaces required for real equipments are reused from hybrid configurations used on EFM and PFM benches.

However, some HW elements may be required specifically for SimEFM, covering interfaces not available on other hybrid configurations (power supply, synchronization signals to equipments, etc…).

On a design point of view, using real equipments on SimEFM brings a hard real-time constraint for the generation of equipment's command and control signals. To handle this, the SimEFM simulator is configured differently compared to a classical numerical simulator:

- All the software is executed using a real-time operating system. Astrium SimEFM runs on a *RedHawk* Linux OS from *Concurrent Computers*, which is also the execution target for hybrid simulators used on EFM/PFM benches.

  The simulation cycles are scheduled under real-time conditions and are synchronized to a reference clock either internally generated, or slaved to a specific external equipment (e.g. GPS).

- The avionics bus interface (e.g. Mil 1553) is directly connected to the *RedHawk* PCI internal bus and all Bus Controller activities are managed in real time in a dedicated task running in parallel of the OBC model.

- The hardware connections used for real equipments acquisition and/or stimulation interfaces can use different technologies. They can be implemented with PCI cards plugged on the internal bus, Ethernet link to dedicated SCOEs or specific Bus Adapter (e.g. PCI/VME).

The main SimEFM hardware elements are the *RedHawk* Linux PC and the avionics bus interface (e.g. Mil 1553). Both are based on COTS (commercials off-the-shelf), bringing to SimEFM its low recurring costs.

The operation of SimEFM can be performed using either the native SimTG Man Machine Interface called SIMOPS (common with numerical simulators) or the AIT Central Check out System (CCS) allowing tests sequences reuse from real EFM/PFM benches and Flight Software Validation system. This combination of both user's interface provides a powerful system for setup and debug.

The SimEFM can also be used in a reduced configuration without models (and no Flight Software), where HW interfaces are directly controlled by the user test sequences. This capability is useful for equipment/instrument integration and early phases characterisation and validation: As soon as possible in the spacecraft development, the electrical compatibility of the equipment can be checked. Later on, as soon as the FSW and the simulation models are validated on numerical systems, the SimEFM can be upgraded to its complete configuration (with OBC model) for functional validation with the equipment under test.

LEON3 SimEFM PROTOTYPE

Based on our latest OBC emulator for LEON3, Astrium has developed a prototype of SimEFM in order to validate the overall concept and feasibility. The main objectives for this prototype were to:

- Demonstrate that several equipments connected to an avionics 1553 bus can be controlled by the SimEFM with a high timing fidelity.
- Demonstrate that AOCS closed-loop tests can be performed on SimEFM with HW AOCS in the loop and gives identical results as the EFM bench.

For this prototype we selected elements from the Astrium AstroBus 250 program. All the simulations, including the OBC model have been directly reused. The Flight Software used on this SimEFM was an already validated version (from EFM).

Two real equipments representative of the AstroBus 250 avionics were integrated : an Inertial Measurement Unit (IMU or Fiber Optic Gyro. –FOG-) and one complex actuator, a CMG unit (Control Moment Gyro). These two equipments were connected to the same Mil 1553 avionics bus.

Associated to these FOG and CMG equipments, their stimulation interfaces (or SCOE) were reused from existing EFM/PFM hybrid configuration. Fig. 3 illustrates the HW configuration for the SimEFM proto.

All operations have been done using existing tests sequences coming from real EFM test benches and were executed on the AIT CCS (Astrium Open Center product).

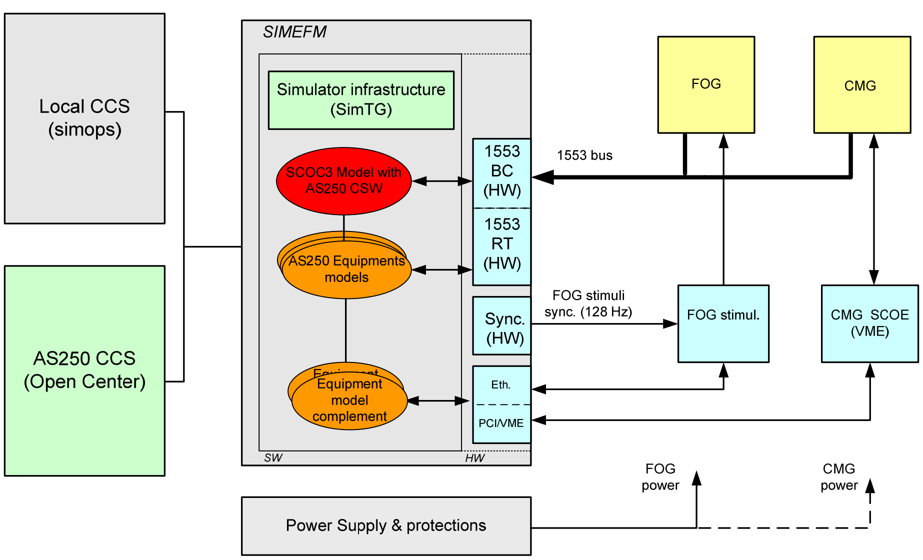

Fig. 3 : SimEFM prototype overview. Two equipments are connected on the 1553 bus, they are also connected to their specific SCOE for stimulation and acquisition needed for closed-loop tests

Both main objectives have been reached by the prototype. The SimEFM generates all 1553 messages on the physical external bus in real time and the two equipments can be controlled as if a real OBC was used. The same test cases (open loop and closed-loop) as EFM bench were run on the configuration.

The timing measurements done on the 1553 traffic showed only few µs (< 3 µs) of discrepancy compared to EFM bench. Fig. 4 illustrates these results, by comparing FOG 1553 exchanges times from both configurations. The period of each message is constant and is close to the reference from EFM. No jitters were measured on SimEFM, giving the proof of hard-real time behaviour of the simulator, including the OBC model and LEON 3 emulator.

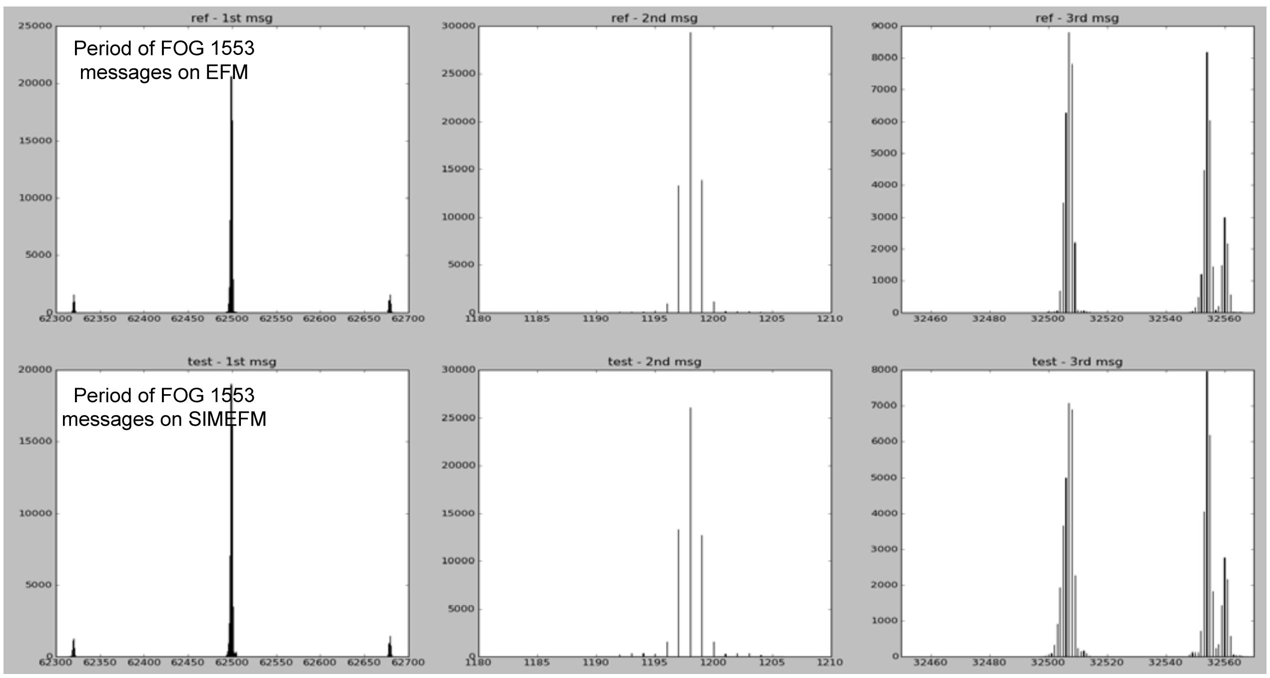

Fig. 4 : FOG 1553 exchanges comparison between EFM and SimEFM. Messages are generated at the same period and without jitter

Both FOG and CMG equipments have been tested with different modes of the FSW, starting with simple equipment management (AOCS function disabled) and ending with a complete AOCS closed-loop test. Fig. 5 illustrates the CMG control by the SimEFM during a gimbal manoeuvre where one CMG was real and the 3 others were simulated.

In addition to technical results, the prototype also demonstrated its versatility in the operation of the system. The test sequences setup on SimEFM can be done in a full simulated environment where no hardware parts are involved. As soon as the sequence is operational, a unique software flag configures the simulator in SimEFM mode and the same test is executed with real hardware. This is very efficient for AIT team in the phase of tests procedures preparation and during equipment integration and equipment/SCOE coupling tests.

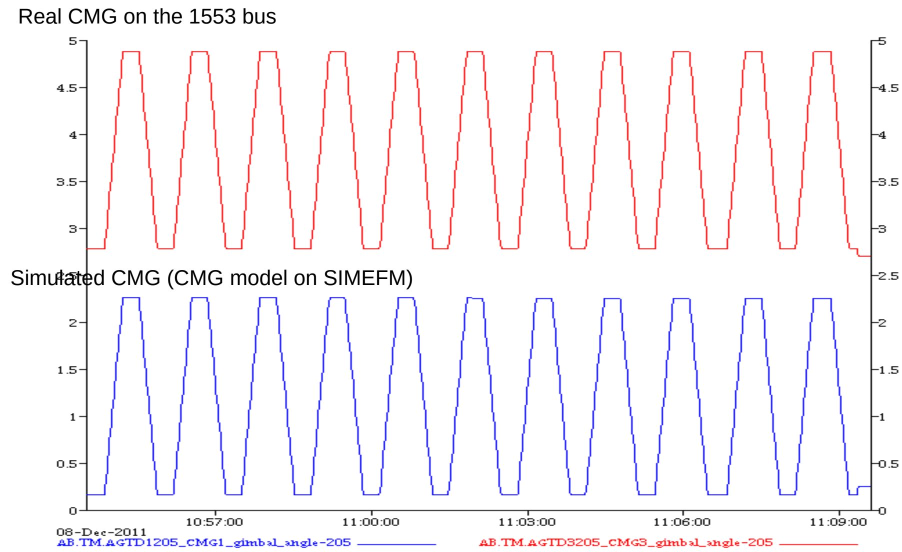

Fig. 5 : Example of TM generated by SIMEFM during a test involving one real CMG and 3 simulated CMG. No differences exist on TM sent by the SimEFM

SimEFM USE CASES

As a new test configuration, SimEFM offers opportunities for the improvement of the Functional Validation process. Different use cases for SimEFM are identified:

For classical spacecraft platform AIV Program:

- SimEFM shall reduce work-load on EFM bench. Activity on the EFM is a bottleneck during Avionics Validation and Functional Validation. Duplicating EFM bench configuration introduces heavy costs due the complexity of the hardware. Cost and manufacturing schedule for a real OBC taking a major part on this. The use of a SimEFM in parallel of EFM will efficiently support part of EFM workload with low recurring costs, decreasing the number of real OBCs necessary to the project for all validation activities.

- Effort and Planning Reduction per test. The setup and configuration management (FSW upload, EGSE usage) on an EFM bench is much more complex than on a SimEFM, where all test sequences can be validated without the use of real hardware.

- Optimization and flexibility of the AIV Process regarding equipments availability. To tackle conflicting equipments schedules (availability, delivery date), a specific test configuration can be setup for different equipment without any conflict with the EFM bench.

- “Low cost” maintenance bench in replacement of the EFM or Avionic Test Bench. No need for a complete OBC, critical equipments can be connected and used with the SimEFM.

At Equipment/Payload/Instrument level:

- SimEFM can be used as a test bench for equipments/payload in a product line. Pre-coupling tests and representative HW/SW and system validation tests can be performed directly at supplier premises.

- SimEFM can be used to validate complex “smart” subsystem with a representative SW and Database environment.

- Early coupling activities between equipment and their external stimulation SCOE (e.g. STR with optical/electrical Stimulator, GNSS receiver with GPS/GNSS constellation simulator, etc…).

At project management level, in case of a complex industrial organisation:

- Risk Mitigation in industrial work sharing. SimEFM can reduce the number of complex test benches like EFM or Avionic Test Benches.

- Deployment on supplier site in order to pre-test FSW-SRDB / equipments compatibility.

CONCLUSION

The SimEFM test configuration is able to reduce drastically test costs and planning during a functional validation. It provides, as well, the ability to perform pre-coupling activities (FSW/HW) with equipments on the critical path and will bring efficient and low-cost training to AIT team in order to prepare for satellite activities.

In addition, and specifically in a complex industrial project organisation, SimEFM benches can be easily deployed at subcontractors level (e.g. payloads manufacturers) for early HW/SW coupling tests with the real flight software and system database (SRDB).

SimEFM, by combining state of the art technologies from Astrium numerical simulators and Electrical Ground System offers opportunities to reduce costs and schedule on future space programs.